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## Comparison study on Chebyshev and Composite lowpass Filter for Harmonic Rejection in Two Ways Radio

Liew Hui Fang<sup>a,\*</sup> and Syed Idris Syed Hassan<sup>a</sup>

<sup>a</sup>*School of Electrical System  
Universiti Malaysia Perlis  
Pauh Putra, 02600 Perlis*

### Abstract

The paper is on a comparison study on Chebyshev and Composite lowpass filter designed at 300-400MHz used for harmonic rejection in two ways radio. The filter is used to attenuate harmonic that generated by power amplifier to prevent from radiating out through the antenna. The filter's circuits were first simulated using Advanced Design Software (ADS) to obtain the best filter characteristic based on S-parameter to see whether they met the specification for two way radio or not using the tuning and optimization features in ADS. The final low pass filter circuits were fabricated using chip capacitor and chip inductor components on printed circuit board. The S-parameter were measured using network analyzer. It was found that the fabricated had similar trend as simulated one. However, the cutoff frequencies are slightly different from what are intended to design. The simulated result showed the composite filter was found to be the best low pass filter and able to perform the better filters response. On the other hand, the fabricated Chebyshev filters was found to be the better filter output response.

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**Keywords:** Radio Frequency (RF); Two ways radio; Harmonic Filter; Communication.

### 1. Introduction

Generally, the two way radios have two channels, one is for transmitter and the other is receiver. It can transmit and receive the signal in two ways, whereas a broadcast receiver which only has one channel able to receives content signal in one way. A two way radio mostly beside it, have push to talk (PTT) button is often present to activate the transmitter when the button is push or otherwise it receives signal with same frequency. The two- way radio can be categories into many types besides those walkie-talkies that still have mobile and stationary base configurations. A two-ways radio can transfer signal in two type of data system, which is analogue and digital system. The two ways radio experience harmonic produced by the transmitter and entering the receiver.

These will damage the receiver circuit. In order to solve this, a low pass filter is to be employed such that it will attenuate the harmonic signal and allow the wanted signal to pass through antenna with minimum losses. By this method, the harmonic filter is also used to attenuate the excessive harmonic that generated by transmitter chain. As the frequency is

\* Corresponding author. E-mail address: [Alicefang88@yahoo.com](mailto:Alicefang88@yahoo.com)

increasing, lumped elements become less and less ideal and all parasitic elements such as series resonances of inductors and parallel resonances of capacitors, and of course all resistive contributions will be the most concerned issue. This will affect the output performance of the low pass filter. As we know, normal lumped inductors and capacitor components introduce stray capacitance and inductance from leads. The distributed element model is more accurate but more complex than the lumped element model. However, the distributed element cannot be used because the frequency is below 1000MHz and the circuit is becoming large at frequency below 1000MHz. The appropriate components are chip capacitor and chip inductor. However the exact values are not available.

## 2. Theory

### 2.1 Composite Low Pass Filter Design

The composite low pass filter was designed for cutoff frequency of 450MHz and impedance of 50 ohm. The important network's sections that constituting the composite filter is shown in Figure 1. It consists of a constant -K filter section, m-derived section and matching section at the input and output.

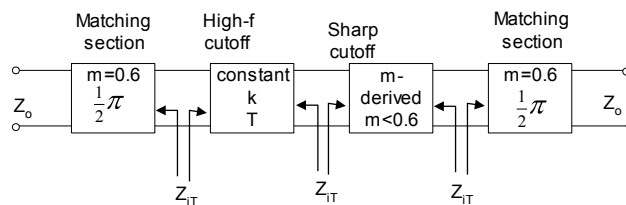


Fig. 1. Block diagram of circuit component in composite filter [1]

### 2.2 Constant -k T – section

The nominal characteristic impedance of constant –k section is made constant value for the assigned frequency which is given by [1,2,3]

$$Z_0 = \sqrt{\frac{L}{C}} = k \quad (1)$$

Using Equation (1), the equation can be rewritten as follows

$$C = \frac{L}{Z_o^2} \quad (2)$$

Or

$$L = CZ_o^2 \quad (3)$$

The cutoff frequency is defines as[11]

$$\omega_c = \frac{2}{\sqrt{LC}} \quad (4)$$

We can rewrite

$$L = \left( \frac{2}{\omega_c} \right)^2 \frac{1}{C} \quad (5)$$

Or

$$C = \left( \frac{2}{\omega_c} \right)^2 \frac{1}{L} \quad (6)$$

By substituting Equation (2) or (3) into Equation (5) and (6), we have [1,2]

$$L = 2Z_o / \omega_c \quad (7)$$

$$C = 2 / Z_o \omega_c \quad (8)$$

Equation (7) and (8) can be used to determine the value of C and L of the T network circuit as shown in Figure 2 to be used in the filter .

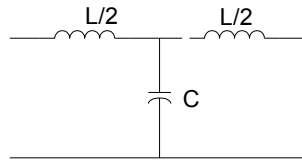


Fig. 2. Low pass constant-K filter section in T-network [1]

### 2.3 For $m$ -derived T Section Sharp Cutoff

The infinite attenuation occurred at frequency  $\omega_\infty$  and given by [11]

$$\omega_\infty = \frac{\omega_c}{\sqrt{1-m^2}} \quad (9)$$

So using Equation (9) to calculate the sharp cutoff  $\omega_{op}$  which relate the value of  $m$  for the  $m$ -derived T-section and it can be written as [11],

$$\omega_{op} = \sqrt{1-m^2} \omega_c \quad (10)$$

Rearrange for  $\omega_c$  and substituting, and we have  $m$  as,

$$m = \sqrt{1 - (\omega_c / \omega_{op})^2} \quad (11)$$

An  $m$ -derived low pass –T-section is given as shown in Figure 3 below.

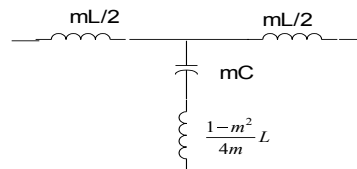


Fig. 3  $m$ -derive T-section [1]

The new inductance and capacitance values can be calculated using [1,2]

$$C' = mC \quad (12)$$

$$L' = \frac{1-m^2}{4m} L \quad (13)$$

Series component

$$L'' = \frac{mL}{2} \quad (14)$$

Where L and C are the same value as k-constant section.

## 2.4 Matching Section

The matching networks are using  $m=0.6$  bisected  $-\pi$  section as shown in Figure 4.[1,4]

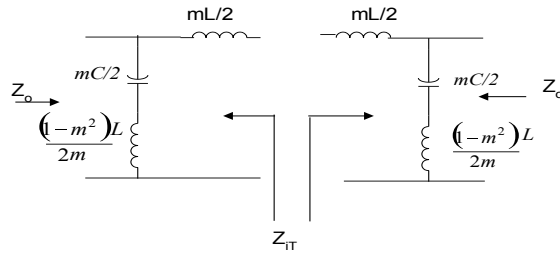


Fig. 4 Bisected  $\pi$ - matching section [1]

The new value for inductor and capacitor as calculated ,

$$L' = \frac{mL}{2} \quad (15)$$

$$C'' = \frac{mC}{2} \quad (16)$$

$$L'' = \frac{1-m^2}{2m} L \quad (17)$$

By combining in cascade the constant  $-K$  section ,  $m$ -derived sharp cutoff and the  $m$ -derived bisected- $\pi$  matching section, the composite filter can be realized[1]. The sharp-cutoff section with  $m < 0.6$  places an attenuation poles near the cutoff frequency to provide a sharp attenuation response , the constant- $K$  section provides the high attenuation further into stopbands. The bisected  $\pi$ - section at the ends of filter match the nominal source and load impedance,  $Z_o$  to the internal image impedance of the constant- $K$  section and  $m$ -derived section. [1,4]

## 2.5 Design of Chebyshev Low Pass Filter

The design of Chebyshev Low Pass Filter was simply based on ladder network as shown in Figure 5. The online calculator is easily accessible from open source.[5,6]

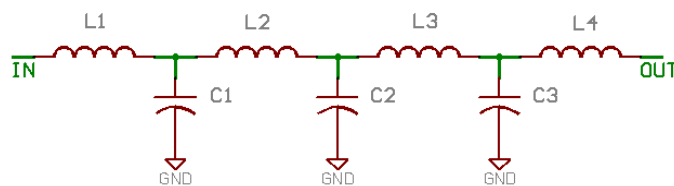


Fig. 5. The 7 poles circuit design by filter calculator

A microstrip line is used to interconnect the components since wiring will introduce stray inductance and maintain the nominal characteristic impedance. The formula used are given below [1]

For  $W/h \leq 1$ :

$$Z_o = \frac{60}{\sqrt{\epsilon_{ff}}} \ln \left( 8 \frac{h}{W} + 0.25 \frac{W}{h} \right) \quad (15)$$

Where

$$\epsilon_{ff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ \left( 1 + 12 \frac{h}{W} \right)^{-1/2} + 0.04 \left( 1 - \frac{W}{h} \right)^2 \right] \quad (16)$$

For  $W/h \geq 1$

$$Z_0 = \frac{120\pi/\sqrt{\epsilon_{ff}}}{\frac{W}{h} + 1.393 + 0.667 \ln\left(\frac{W}{h} + 1.444\right)} \quad (17)$$

Where

$$\epsilon_{ff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{W}\right)^{-1/2} \quad (18)$$

Width:

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left(0.23 + \frac{0.11}{\epsilon_r}\right) \quad (19)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}} \quad (20)$$

$$\frac{W}{d} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & \text{for } W/d < 2 \\ \frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left\{ \ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right\} \right] & \text{for } W/d > 2 \end{cases} \quad (21)$$

Where  $W$  = width of microstrip  
 $h$  = thickness of substrate  
 $\epsilon$  = dielectric constant

### 3. ADS Simulation and Results

The two types of low pass filter circuits were designed according the specification at frequency cutoff 400MHz with insertion loss less than -1 dB, return loss 15dB and attenuation at  $2 f_c$  more 45dB . Both were simulated in ADS software using the lumped-components (capacitor and inductor). First the simulation was done using inductor and capacitor values as per design. But,seem the simulation resultsdid not meet the specification values, tuning method was performed by try and error to change some of parameter values until the simulation result close to specification. Figure 6 and Figure 7show circuit schematic diagram in ADS software.

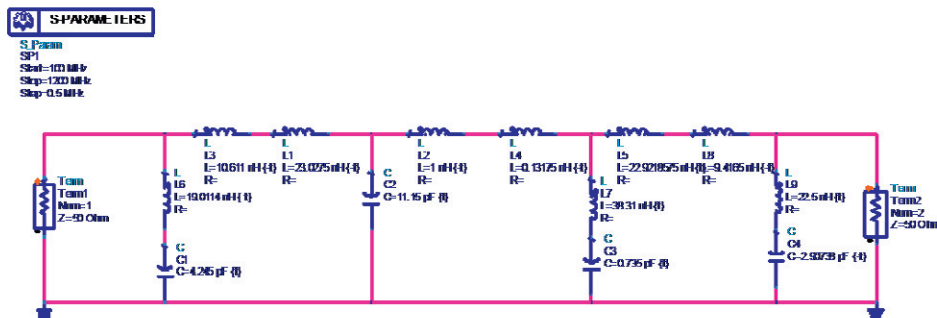


Fig. 6. ADS schematic design of composite filter

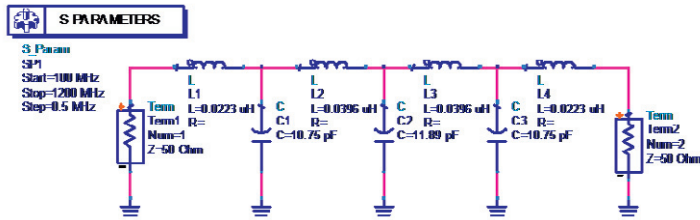


Fig. 7. ADS schematic design of Chebyshev filters

The simulation result of S-parameter for composite filter, before and after tuning are shown in Figure 8. Table 1 is summarizing the results for two cutoff frequency 300MHz and 400MHz respectively.

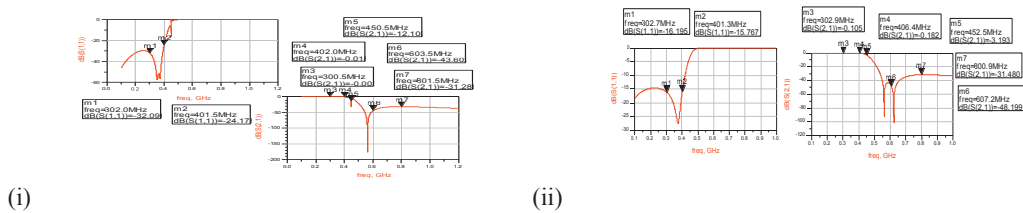


Fig. 8. Simulation result for composite filter (i)Composite filter before tuning (ii) Composite filter after tuning

Table 1. The Table About the Simulation Result Composite Filter Before and After Tuning Cutoff at 450MHz on ADS

Items	S <sub>11</sub> (dB)		S <sub>21</sub> (dB)				
	Tx-input return loss		Tx-insertion loss		2fc attenuation		-3dB cutoff
Cutoff freq(MHz)	300	400	300	400	600	800	450
Before tuning	-32.10	-24.17	-0.003	-0.018	-43.60	-31.29	-2.10
After tuning	-16.20	-15.77	-0.105	-0.182	-48.20	-31.48	-3.19
Spec value	<-15	<-15	>-1	>-1	<-54	<-45	-3.0

The simulation result of S-parameter for Chebyshev filter, before and after tuning are shown in Figure 9. Table 2 is summarizing the results for two cutoff frequency 300MHz and 400MHz respectively.

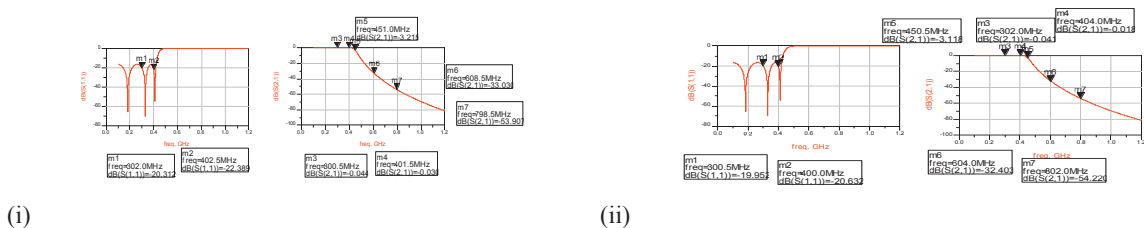


Fig. 9. Simulation result for Chebyshev filter ; (i)Chebyshev filters circuit before tuning and cutoff at 450MHz (ii)Chebyshev filters circuit after tuning and cutoff at 450MHz

Table 2. The Table About The Simulation Result Chebyshev Filters Before and After Tuning Cutoff at 450MHz on ADS

Items	S <sub>11</sub> (dB)		S <sub>21</sub> (dB)		
	Tx-input return loss		Tx-insertion loss	2fc attenuation	-3dB cutoff

Cutoff freq(MHz)	300	400	300	400	600	800	450
Before tuning	-20.31	-22.39	-0.044	-0.030	-33.03	-53.91	-3.215
After tuning	-19.95	-20.63	-0.041	-0.018	-32.40	-54.22	-3.118
Spec value	<-15	<-15	>-1	>-1	<-54	<-45	-3.0

#### 4. Fabrication and Measurement Results

##### 4.1 Composite low Pass Filters cutoff at 450MHz

Using ADS, the circuit layout for PCB was created as shown in Figure 10. The components are placed and soldered on the appropriate component foot print on microstrip line.

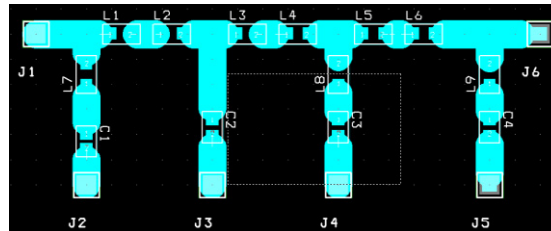


Fig. 10. Layout design for composite filter

After measuring the S-parameter using network analyzer, the results are shown in Figure 11 for  $S_{11}$  and Figure 12 for  $S_{21}$ . The other results are tabulated in Table 3. The results seem to follow the same trend as the simulated results.

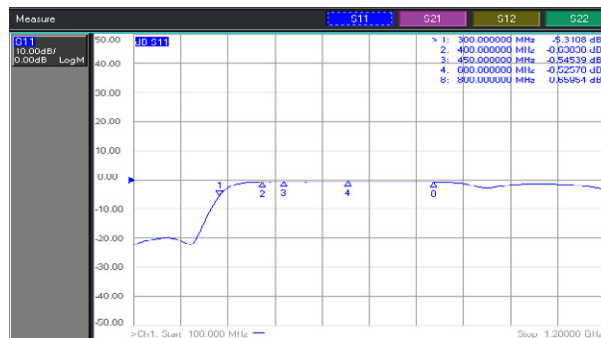


Fig. 11. Measuring  $S_{11}$  result for Composite low Pass filters

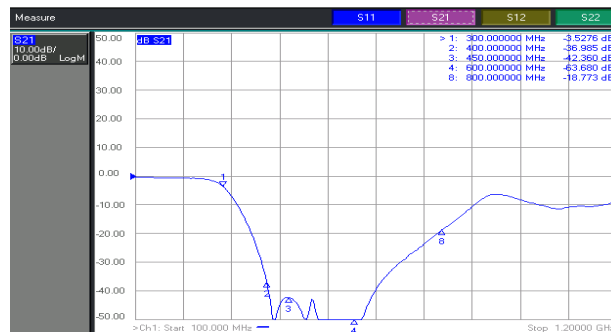


Fig. 12. Measuring  $S_{21}$  result for Composite Low Pass Filters

Table 3 Simulation S-Parameter Results For Composite Low Pass Filters On Hardware Measurement

Items	$S_{11}$ (dB)	$S_{21}$ (dB)
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	<i>Tx-input return loss</i>		<i>Tx-insertion loss</i>		<i>2fc attenuation</i>		<i>-3dB cutoff</i>
Cutoff freq(MHz)	300	400	300	400	600	800	450
Measured value	-5.31	-0.638	-3.53	-36.99	-63.68	-18.77	-42.36
Spec value	<-15	<-15	>-1	>-1	<-54	<-45	-3.0

#### 4.2 Chebyshev Low Pass Filter Cutoff At 450MHz

Similarly the circuit layout was created using ADS as shown in Figure 13. The measured results are shown in Figure 14 for  $S_{11}$  and Figure 15 for  $S_{21}$ . Other results are tabulated in Table 4. It is found that the results follow the trend as the simulated one. It seemed that the results are much better than the composite filter.

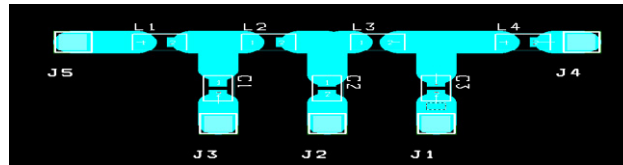


Fig. 13. Layout design for Chebyshev filter

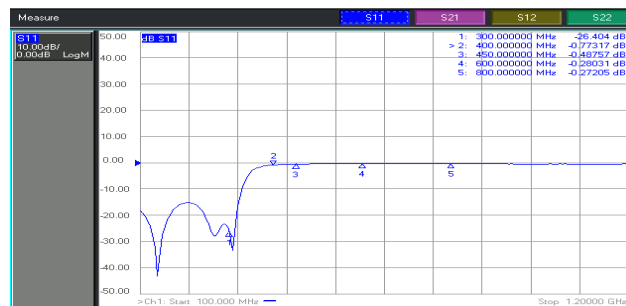


Fig. 14. Measuring  $S_{11}$  result for Chebyshev low pass filter



Fig. 15. Measuring  $S_{21}$  result for Chebyshev low pass filter

Table 4. Simulation S-Parameter Results For Chebyshev Low Pass Filters On Hardware Measurement

Items	S <sub>11</sub> (dB)		S <sub>21</sub> (dB)				
	Tx-input return loss		Tx-insertion loss		2fc attenuation		-3dB cutoff
Cutoff freq(MHz)	300	400	300	400	600	800	450
Measured value	-26.4	-0.773	-1.30	-20.98	-59.83	-66.03	-32.58
Spec value	<-15	<-15	>-1	>-1	<-54	<-45	-3.0

## 5. Conclusion

From the simulation results, it is noticed that the composite filters give a good characteristic and able to perform the



better filters response and all the S-parameter value are appropriated to the specification value required for filter design. However for fabricated low pass filters, Chebyshev filters seemed to produce the better filter output response.

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